

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3432

CIRCUMFERENTIAL DISTRIBUTION OF PROPELLER-SLIPSTREAM
TOTAL-PRESSURE RISE AT ONE RADIAL STATION
OF A TWIN-ENGINE TRANSPORT AIRPLANE

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SUMMARY

Flight tests on a twin-engine transport airplane have been made to determine the effects of fuselage-nacelle interference on the circumferential distribution of the rise in total pressure at one radial station behind the propellers. The effects of this flow interference on the operation of a simple propeller-thrust indicator, which samples the total-pressure rise at two diametrically opposed points in the slipstream (to counteract the effects of variations in angles of pitch and yaw), have been investigated.

Fuselage-nacelle interference is shown to be the cause of apparent differences in indicated thrust between powerplants operating under presumably similar conditions. Proper placement of the thrust-indicator total-pressure sensing elements eliminates the discrepancies for any preferred flight condition, with only small residual effects remaining at other flight conditions. Thrust indicators installed for comparison purposes in the cruise condition may, for example, be useful as a sensitive means of controlling engine output and airplane trim while still serving as a reliable safety device in all other flight conditions.

INTRODUCTION

As a result of several serious airplane accidents attributed to inadvertent propeller reversal, considerable effort is being directed toward the development of a suitable warning device. In any situation, such as an inadvertent propeller reversal, engine failure, or propeller-governor malfunction, the immediate danger arises primarily from the sudden large asymmetrical changes in thrust which may occur. These thrust changes may cause complete loss in airplane control. Because of the direct connection between thrust and safe airplane operation, some form of thrustmeter appears desirable.

A particularly simple type of thrust indicator was presented at the Air Transport-Safety Session, Twenty-First Annual Meeting of the IAS in New York on January 26-29, 1953. An elaboration of this presentation is given in reference 1. This thrustmeter is a simplification of an experimental method of determining propeller thrust which has been in use for many years (refs. 2 to 6). The theoretical equations describing the conversion of measurements of the rise in total pressure to thrust are given in reference 5. The simplification consists of replacing a multiplicity of total-pressure tubes with two diametrically opposed tubes, the use of two tubes being considered necessary to compensate for the effects of angles of pitch and yaw (refs. 7 and 8). In the process of replacing a multiplicity of total-pressure tubes with only two tubes, an accurate means of determining thrust is replaced by an index of thrust. The placement of the pair of tubes therefore becomes important.

As reported in reference 1, preliminary tests with vertically orientated total-pressure tubes were conducted on a C-45 airplane. Since that time, similar installations have been made on several other types of airplanes and a significant amount of service experience has been accumulated. These trials have all demonstrated the value of the simple thrust indicator as a warning device for sudden changes in propeller thrust.

With the vertical orientation of total-pressure tubes used in the trials, differences of 5 percent to 10 percent in indicated thrust were often observed between engines operating under presumably identical conditions. These differences depended on the flight condition and were not random inasmuch as they were repeatable.

Although the observed differences in indicated thrust were insignificant with respect to the use of the indicator as a warning device, differences in indications would be objectionable, for example, in application of the instrument to cruise control. For cruise control, it would appear necessary that each indicator show the same thrust for the same engine power output.

It is evident that the air flow into the propellers is nonuniform due, primarily, to fuselage-nacelle interference. A large amount of research has been done on fuselage-nacelle interference in relation to the 1-per-revolution propeller vibratory problem. (Ref. 9, for example, presents an extensive series of measurements.) Although nonuniform, this flow will tend to be symmetrical with respect to the plane of symmetry of the airplane. Difficulty arises, however, when propellers are made to rotate in this flow in the same direction, antisymmetrical with respect to the plane of symmetry. Preliminary calculations indicated that this effect could account for the discrepancies previously noted.

The purpose of this report is to present the results of a direct investigation of the effect of fuselage-nacelle interference by means of measurements of total-pressure rise made circumferentially at one radial station behind similarly rotating propellers of a twin-engine transport airplane. These measurements are used in a brief analysis to determine whether the thrust differences previously observed may be eliminated by reorientation of the total-pressure tubes.

SYMBOLS

V_{is}	service indicated airspeed, mph
Ω	angular position about thrust axis, measured counter-clockwise from upper vertical position as seen from front, deg
Δp_T	difference between total pressure in propeller wake and total pressure from copilot's service airspeed system, in. H_2O
ψ	yaw angle, positive for right yaw or left sideslip, deg

AIRPLANE AND APPARATUS

The airplane used for this investigation was a twin-engine transport airplane with R-1830-90C engines, a front view of which is shown in figure 1.

Each total-pressure rake consisted of a ring of 12 total-pressure tubes mounted on each engine nacelle as shown in figures 2 and 3. Slipstream total-pressure rise was determined directly by recording the difference between total pressure sensed by each survey tube and reference total pressure obtained from the copilot's side of the standard airspeed system of the airplane. The recording multiple manometers available for this investigation had a range of ± 10 in. H_2O . Measured pressures are estimated to be accurate to within 0.2 in. H_2O .

Airplane angles of attack and yaw were measured by vanes mounted on a boom extending forward from the nose of the airplane as shown in figure 4.

Airspeed and altitude as sensed by the standard airplane system were also recorded.

Dimensions pertinent to this investigation are shown in figure 5. Other specifications of interest are as follows:

Engines (two) Pratt and Whitney R-1830-90C Twin Wasp, with
right-hand rotation

Propellers (two): Hamilton Standard three-blade hydromatic quick-
feathering with constant-speed control

Blade design 6477A-0 (wide)

Reduction-gear ratio 16:9

Tip clearance between fuselage and propeller, in. $7\frac{1}{4}$

Airplane test weight, lb (approx.) 25,000

Wing:

Area, sq ft 988.9

Incidence, deg 2

Dihedral, deg 5

Aspect ratio 9.13

Airfoil section at root NACA 2215

Airfoil section at tip NACA 2206

Wing flaps (split, trailing-edge):

Total area, sq ft 82

Total span, in. 499

Maximum deflection downward, deg 45

TESTS

In general, the procedure followed in each test was to stabilize flight at the desired speed and power and at an estimated zero angle of yaw. When stabilized conditions were obtained, records were taken at, or in passing through, a pressure altitude of 5,000 feet. During each run the airplane was yawed slightly to the left and right, and, from the resulting time histories, conditions at zero angle of yaw were determined.

All tests were made with both engines adjusted, as nearly as possible, to the same power by using standard airplane instrumentation.

RESULTS AND DISCUSSION

The results of the tests are presented in figures 6 to 10 as the variation of slipstream total-pressure rise with angular position about

the thrust axis for both the left and right engines (designated as engines 1 and 2, respectively). The values of indicated airspeed, manifold pressure, and engine speed are indicated by standard pilot's instruments and are as follows:

Effect of -	Flight conditions	Engine speed, rpm	Manifold pressure, in. Hg	Figure
Airspeed	Full power: $V_{is} = 95$ and 195 mph	2,550	42	6
Wing flaps	Approach: $V_{is} = 110$ mph	2,050	21	7
Power	Cruise: $V_{is} = 163$ mph	2,000	30, 32, and 34	8
Angle of yaw	Cruise: $V_{is} = 155$ mph	2,550	31	9
Engine cowl flaps	Approach: $V_{is} = 110$ mph	2,020	$19\frac{1}{2}$	10

The measurements have been plotted in these figures in a manner to facilitate comparisons between left and right engines on a "mirror image" basis. Although the flow fields in which both propellers operate may reasonably be assumed to be mirror images of each other, it is interesting to observe that the thrust distributions are, in general, quite dissimilar. These observed dissimilarities are caused by the fact that both propellers rotate in the same direction; whereas, in order to preserve symmetry, they would have to rotate counter to each other. These dissimilarities tend to become greater as airspeed is reduced or as power is increased.

Effect of Airspeed at Full Power

The effect of airspeed on the circumferential distribution of thrust was determined by making tests at indicated airspeeds of 95 mph and 195 mph with both engines adjusted to full power (2,550 rpm and manifold pressure of 42 in. Hg). Engine settings were not changed between the low- and high-speed tests. Results of these tests are presented in figure 6.

In addition to the thrust-distribution curves, the average total-pressure rise for each test is also indicated in figure 6. At an indicated airspeed of 95 mph, the average total-pressure rise from both engines is found to agree to within less than 2 percent. At an indicated airspeed of 195 mph, however, the average total-pressure rise for engine 2 is about 8 percent higher than the average total-pressure rise for engine 1. Because of the agreement obtained at low speed and because the engine power settings were not changed, the differences in average total-pressure rise obtained at high speed must be attributed to a radial shift in thrust loading of one engine relative to the other caused by the change in interference flow with respect to airspeed.

Qualitative verification of this supposition has been obtained from an analysis based on the 40-inch radial station of the flow-field data of reference 9. This location corresponds roughly to the surveyed radial station of the present investigation and for flight conditions corresponding roughly to the high-speed condition of the test airplane. By using this flow field, the circumferential distribution of thrust for right and left propellers at the 40-inch station was calculated. The average total-pressure rise from the right engine at the 40-inch radius was found to be about 4 percent higher than that from the left engine, as compared with 8 percent measured in this investigation. When allowance is made for the relatively small fuselage in the tests of reference 9, the agreement is considered to be good.

Effect of Wing Flaps, Approach Condition

The effect of wing flaps on the thrust distribution was determined by making tests in the approach condition (indicated airspeed of 110 mph, engine speed of 2,050 rpm, and manifold pressure of 21 in. Hg) with flaps up and full down. Figure 7 shows that the influence of wing flaps is small. This result is, at first glance, surprising because a considerable change in thrust distribution would be expected to result from the decrease in airplane angle of attack caused by lowering the wing flaps. However, since the propellers are operating ahead of the flaps, the decrease in airplane angle of attack is, to a large extent, compensated by the increase in upwash angle.

Effect of Power, Cruise Condition

In order to determine the sensitivity of total-pressure measurements to changes in engine power output, tests were made in the cruise condition at an indicated airspeed of 163 mph, engine speed of 2,000 rpm, and manifold pressure of 32 in. Hg and at the same airplane and engine speeds but at manifold pressures of 30 in. Hg and 34 in. Hg. These changes in manifold pressure correspond to approximately a 7-percent decrease and a 7-percent increase in engine power output from the original manifold-pressure setting of 32 in. Hg.

Figure 8 shows that, at every surveyed point, the total pressure increases with an increase in engine power and decreases with a decrease in engine power. As also indicated within the accuracies of the instrumentation, a change in total pressure, arising from a change in power, appears to be independent of the point of measurement.

Effect of Angle of Yaw, Cruise Condition

Figure 9 presents the results of tests made in the cruise condition at angles of yaw at -1.5° , 0° , and 2.5° . It is seen that small angles of yaw change the thrust distributions slightly, but, as expected, a change in pressure at any survey point, within the accuracy of measurement, is compensated by an equal change in the opposite direction on the diametrically opposed total-pressure tube. The net effect is to make the average of each pair of opposite tubes essentially independent of angle of yaw.

Effect of Engine Cowl Flaps, Approach Condition

From practical considerations, it seems desirable to mount any total-pressure sensing element of the thrust indicator on a nonremovable portion of the airplane structure. This procedure often requires that the total-pressure tubes be mounted behind the engine cowl flaps. In order to determine whether the cowl-flap setting has any effect on the total-pressure measurements, tests in the approach condition were made with cowl flaps both open and closed. The results of these tests are given in figure 10. As anticipated, no discernible difference was measured. As long as the total-pressure tubes are located away from the wake of the cowl flaps, no difficulty from cowl-flap operation should be experienced.

Thrustmeter-Tube Locations

For a propeller operating in an undistorted flow field at an inclination due to an angle of pitch or yaw, the circumferential distribution of total-pressure rise at a fixed radial station closely approximates a sinusoidal variation. In this situation, the average total-pressure rise sensed by any pair of diametrically opposed total-pressure tubes, whatever the orientation, would be expected to provide a good index of thrust. Operation in an undistorted flow field is approached, for example, by the outboard propellers of typical four-engine transport airplanes. It is also approximated by the propellers in airplanes such as the C-45 airplane of reference 1 where, although close to the fuselage, the propeller disk is very nearly at the nose of the airplane in a region where the flow about the fuselage is not strongly developed.

When the flow field is distorted, as in the present investigation and illustrated by figure 6, the circumferential variation in total-pressure rise is no longer sinusoidal. Although on the average the use of diametrically opposed tubes is still expected to compensate for the effects of angles of pitch and yaw, the orientation of each pair of tubes becomes important. All indicators must be orientated so that essentially the same thrust is indicated for the same engine operating conditions. Since the interference effects are not independent of flight conditions, it is evident that one tube orientation cannot be appropriate to all flight conditions. Therefore, the flight condition under which the most accurate comparisons between powerplants is desired must be determined before a selection of orientation is made.

In figure 11 an orientation is selected with emphasis on the cruise condition; a schematic presentation of this location is presented in figure 12. The thought in this case is to provide the greatest relative accuracy in powerplant control and airplane trim. In this application, emphasis is on efficiency of operation. Slight discrepancies could be tolerated at other flight conditions where a high degree of relative accuracy is not necessary. In other flight conditions, the instrument is used primarily as a safety device and only large thrust differences between engines are of importance. The selection of orientation in figure 11 is made by superimposing the thrustmeter indications (average total-pressure rise of each diametrically opposed pair of tubes) as a function of the angular position of one of the tubes for one engine on that of the other engine. Superposition is made in such a manner that, when a location is selected, the thrustmeter indications are the same for both engines in the cruise condition and not seriously different for other conditions. For the selection made in figure 11, it is seen that good comparability is also obtained at conditions of full power and maximum speed ($V_{1s} = 195$ mph) with a difference in indications of less than 5 percent for the full-power and low-speed ($V_{1s} = 95$ mph) condition. This selection must be tempered by the fact that an accurate measure of engine power was not available and that some final adjustments may be necessary.

Figure 11 illustrates that it is possible to find thrustmeter-tube orientations that will provide equal indications between engines for equal powers for any selected flight condition without, in general, introducing important discrepancies at other conditions. On the other hand, this figure also shows that an injudicious choice of orientations could produce apparent differences in thrust as large as 40 percent.

Although the results of this investigation are, of course, strictly applicable to the test airplane and the specific location of the survey tubes, they should serve as a first approximation for many other applications because of the broad similarities between airplanes with respect to their general fuselage-nacelle arrangement.

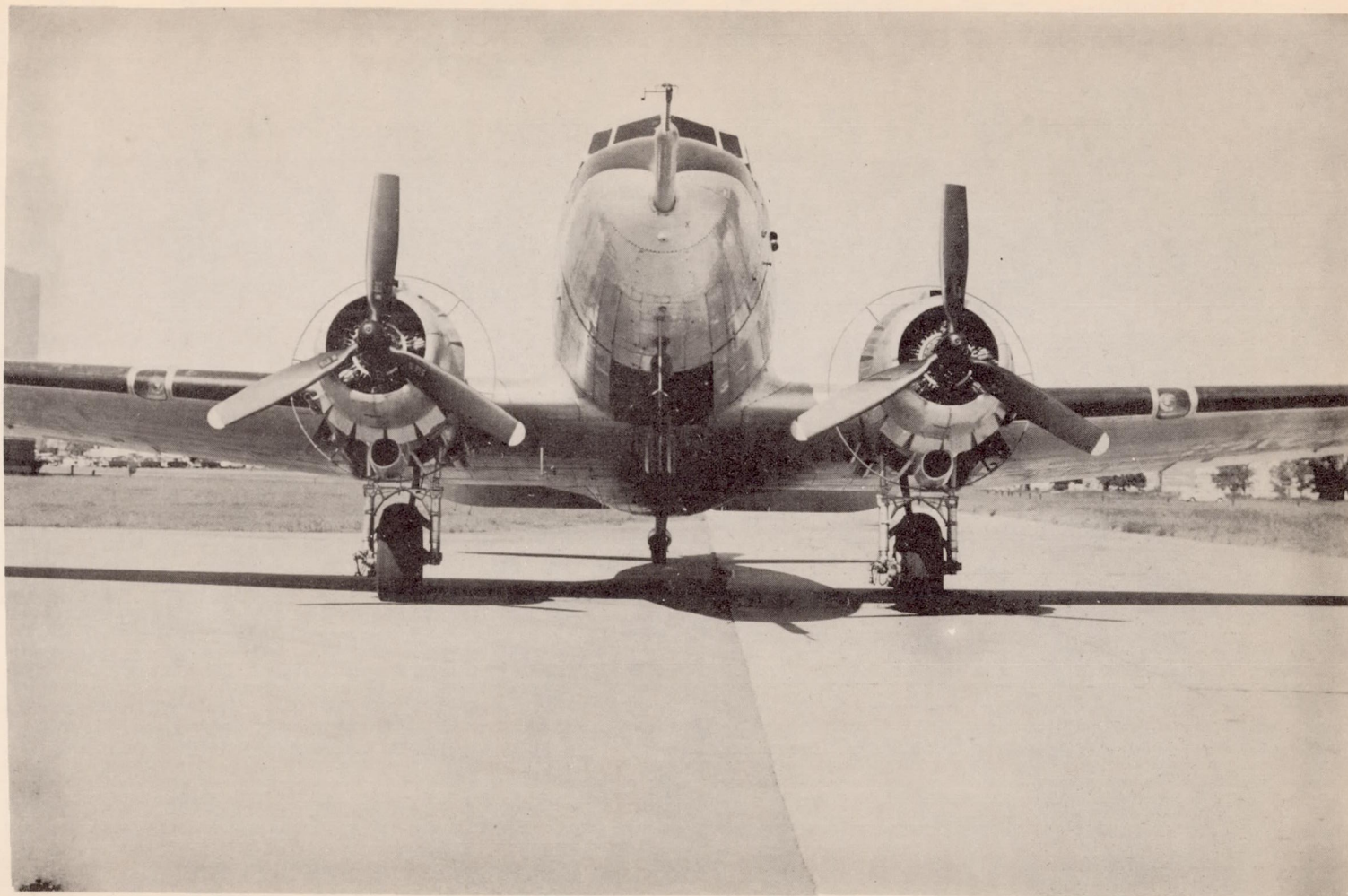
CONCLUDING REMARKS

The flight tests of this report indicate that the apparent differences in indicated propeller thrust between powerplants operating under presumably similar conditions can be attributed to fuselage-nacelle interference and may be eliminated for any selected flight condition by suitable orientation of the total-pressure tubes. In other flight conditions, small residual effects may remain which, however, do not impair the use of the simple thrust indicator as a safety device.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 18, 1955.

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L-81943

Figure 1.- Front view of twin-engine transport airplane.



(a) Front view.

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Figure 2.- Total-pressure survey ring mounted on test airplane.



(b) Side view.

L-81938

Figure 2.- Concluded.

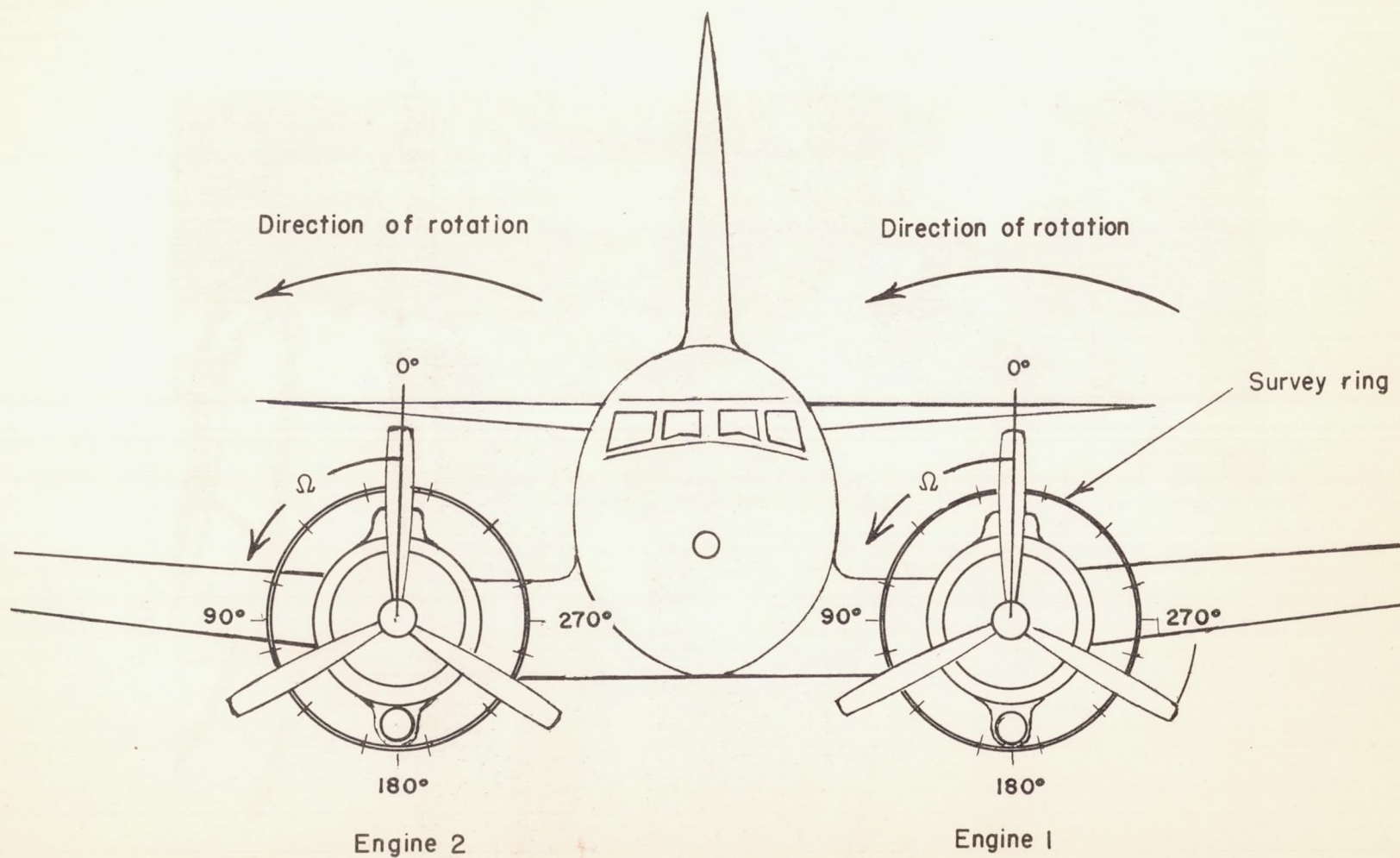
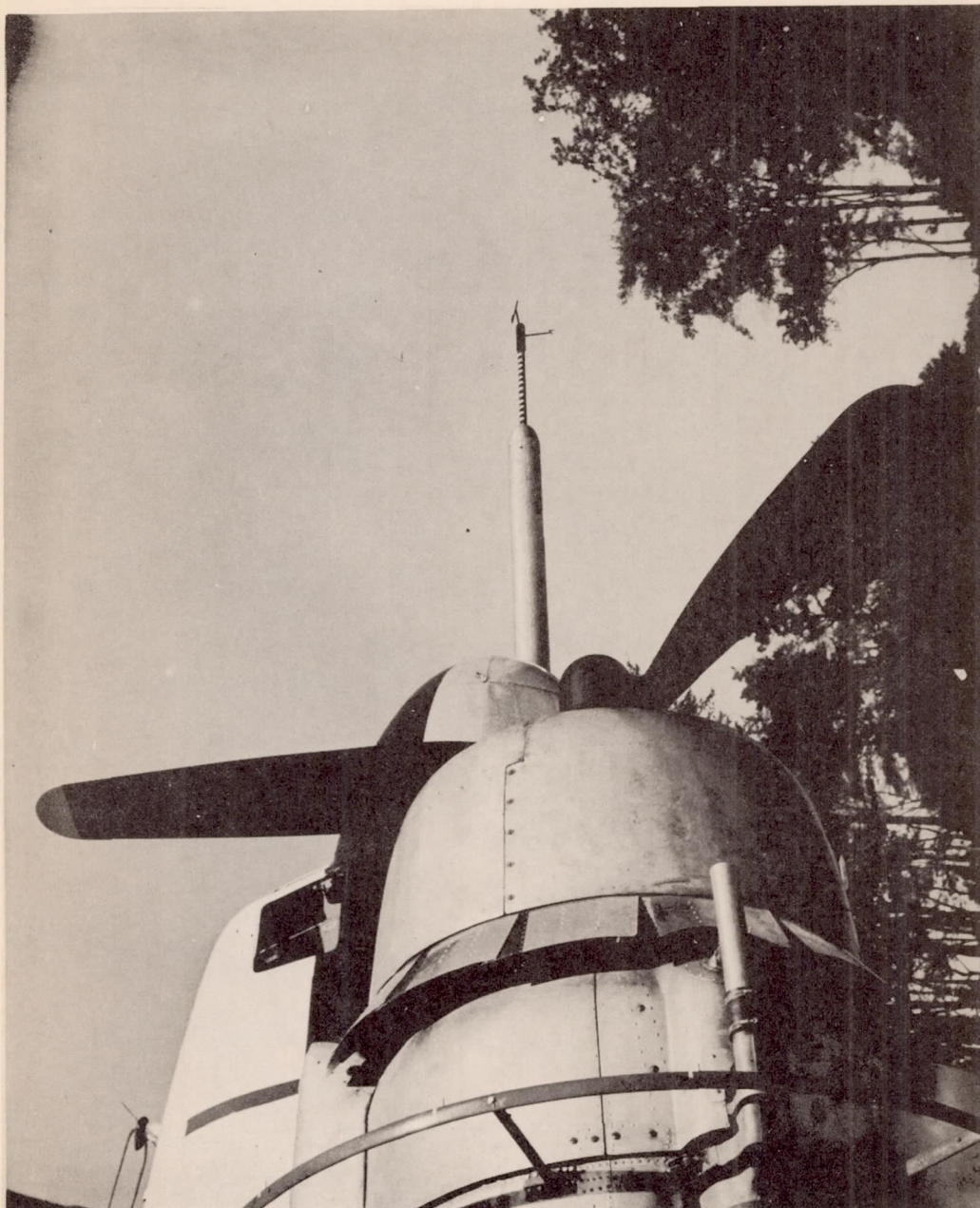
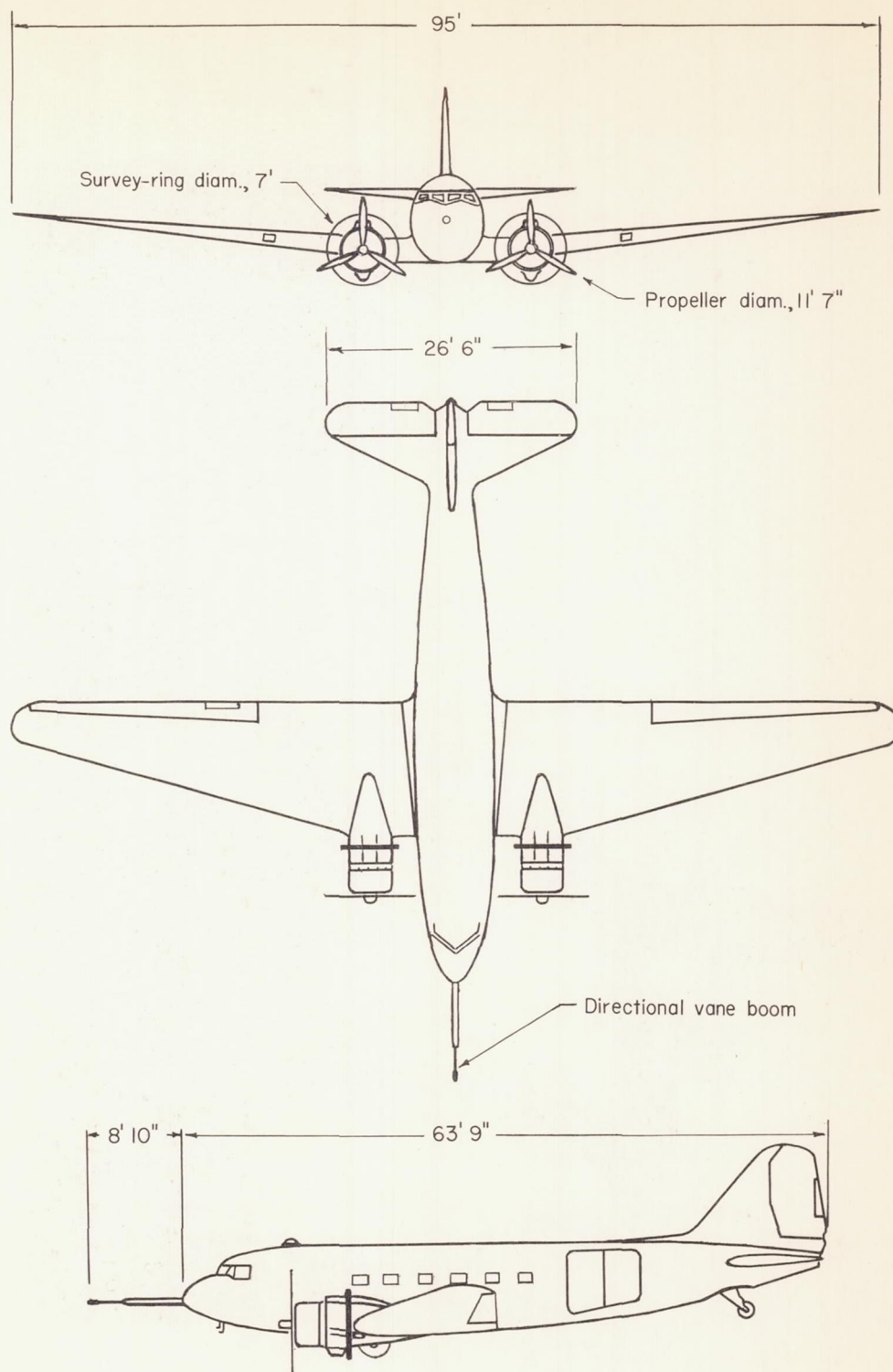


Figure 3.- Geometrical arrangement of survey ring.



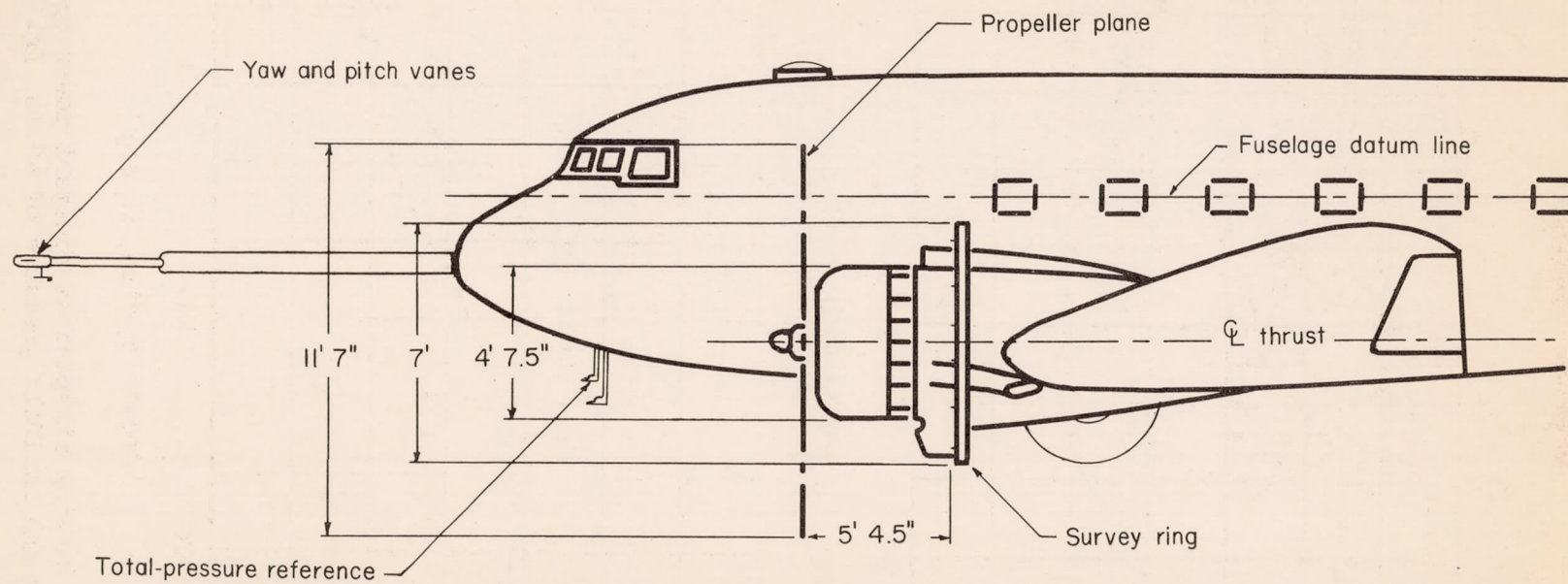
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Figure 4.- Directional vane boom.



(a) Three-view drawing.

Figure 5.- Geometric configuration of twin-engine transport airplane.



(b) Relation of powerplant to survey ring.

Figure 5.- Concluded.

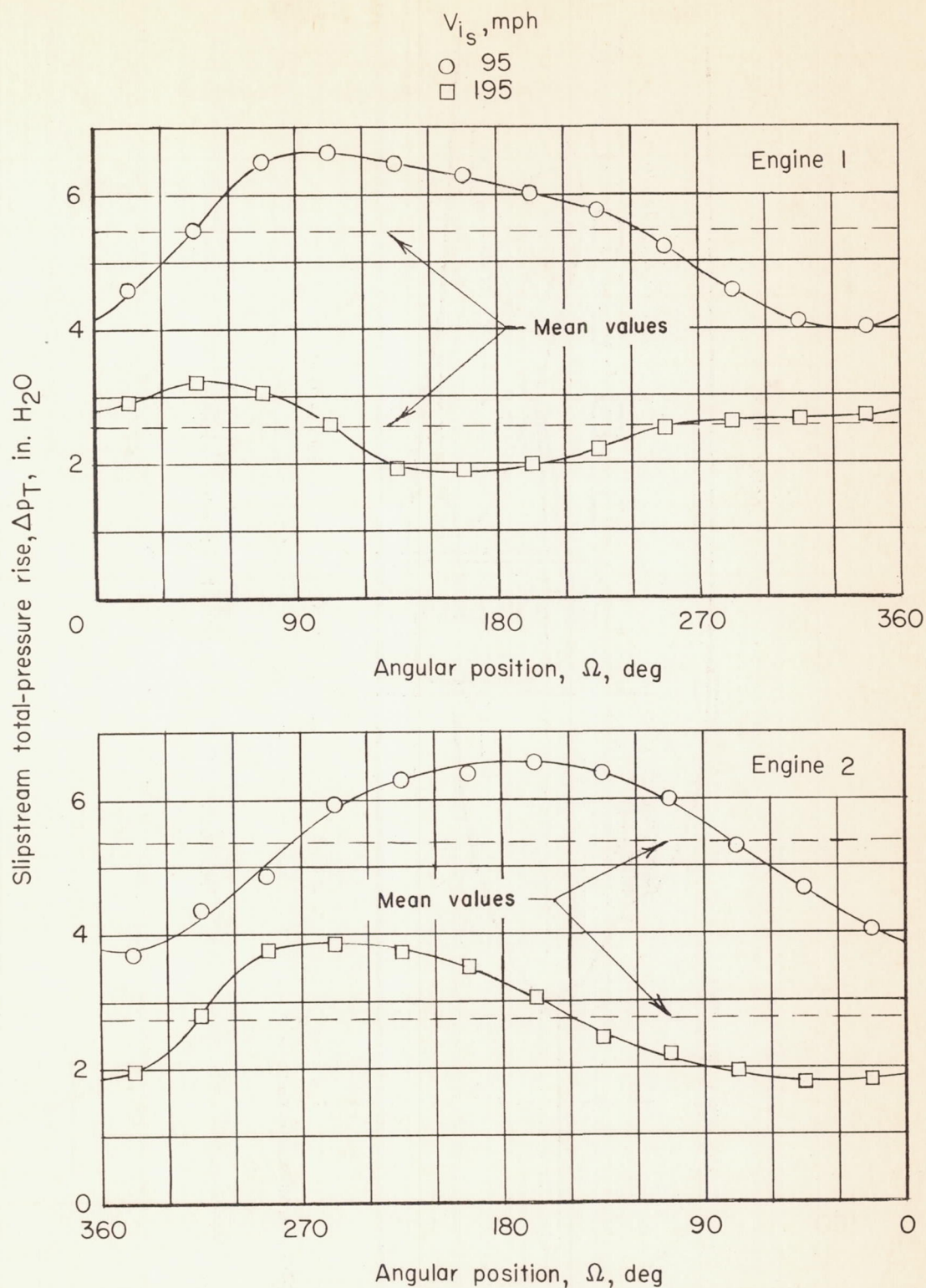


Figure 6.- Effect of varying airspeed at constant power condition of 2,550 rpm and manifold pressure of 42 in. Hg.

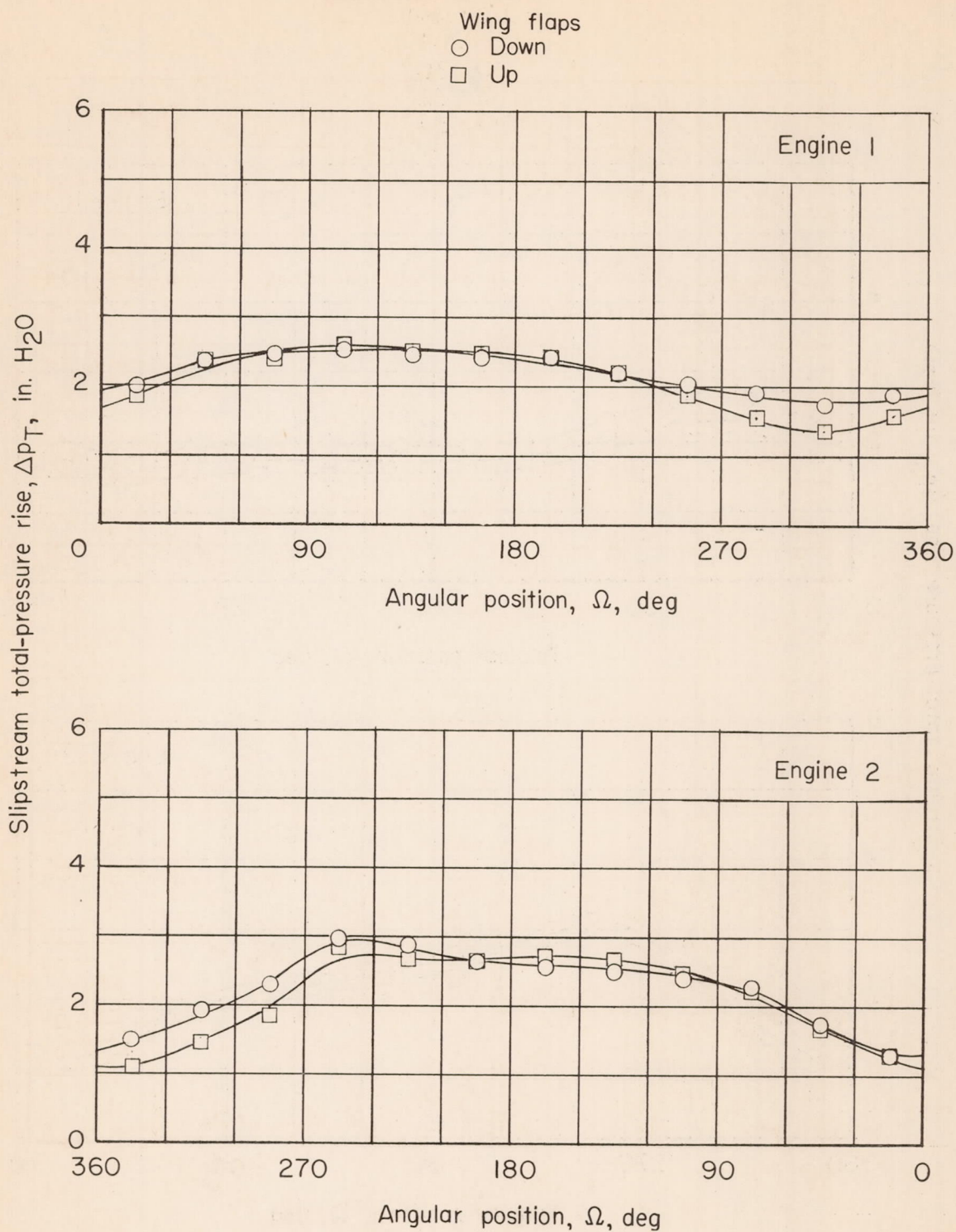


Figure 7.- Effect of wing flaps at approach condition of 2,050 rpm, manifold pressure of 21 in. Hg, and indicated airspeed of 110 mph.

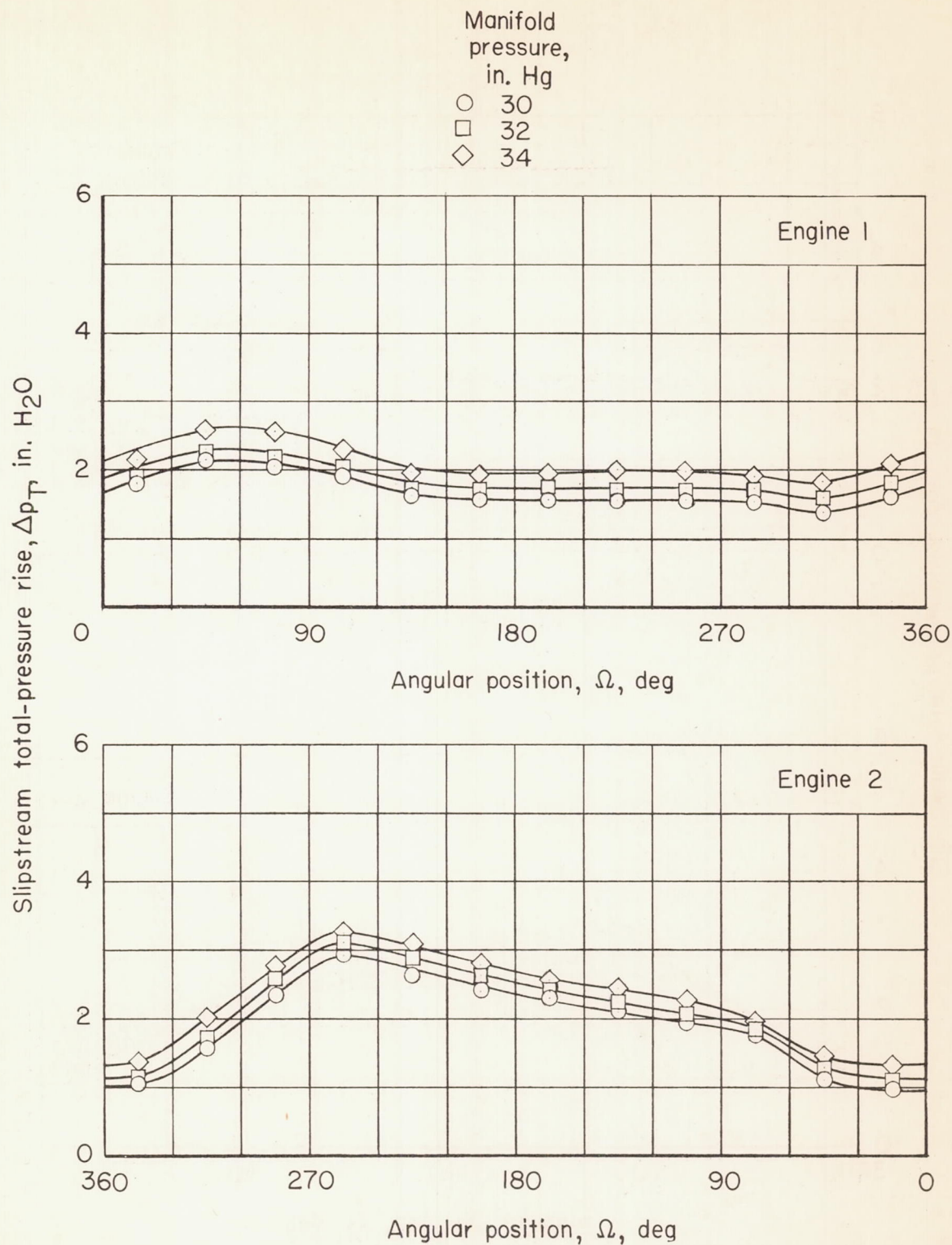


Figure 8.- Effect of varying power at constant indicated airspeed of 163 mph and engine speed of 2,000 rpm.

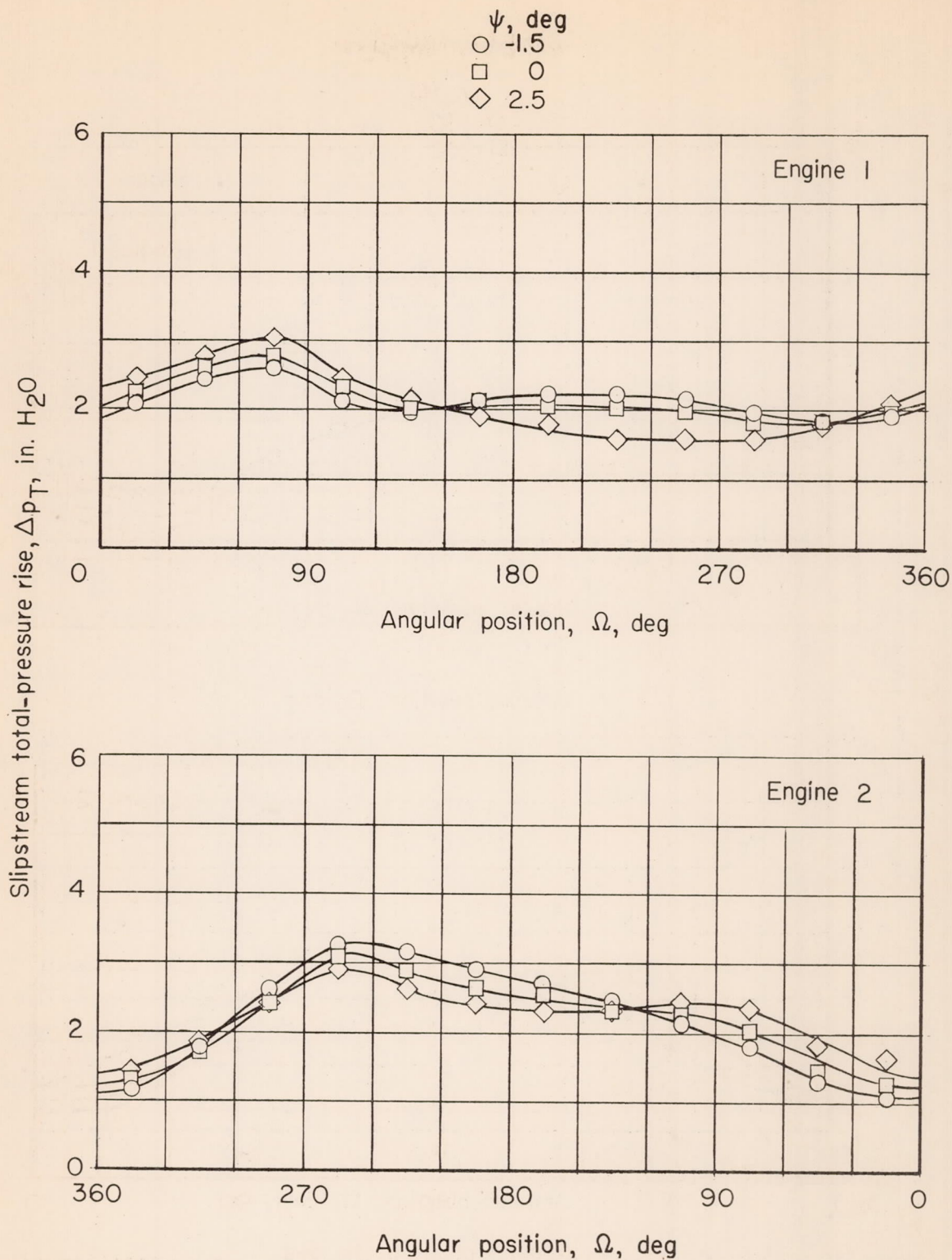


Figure 9.- Effect of angle of yaw at constant power condition of 2,550 rpm, manifold pressure of 31 in. Hg, and indicated airspeed of 155 mph.

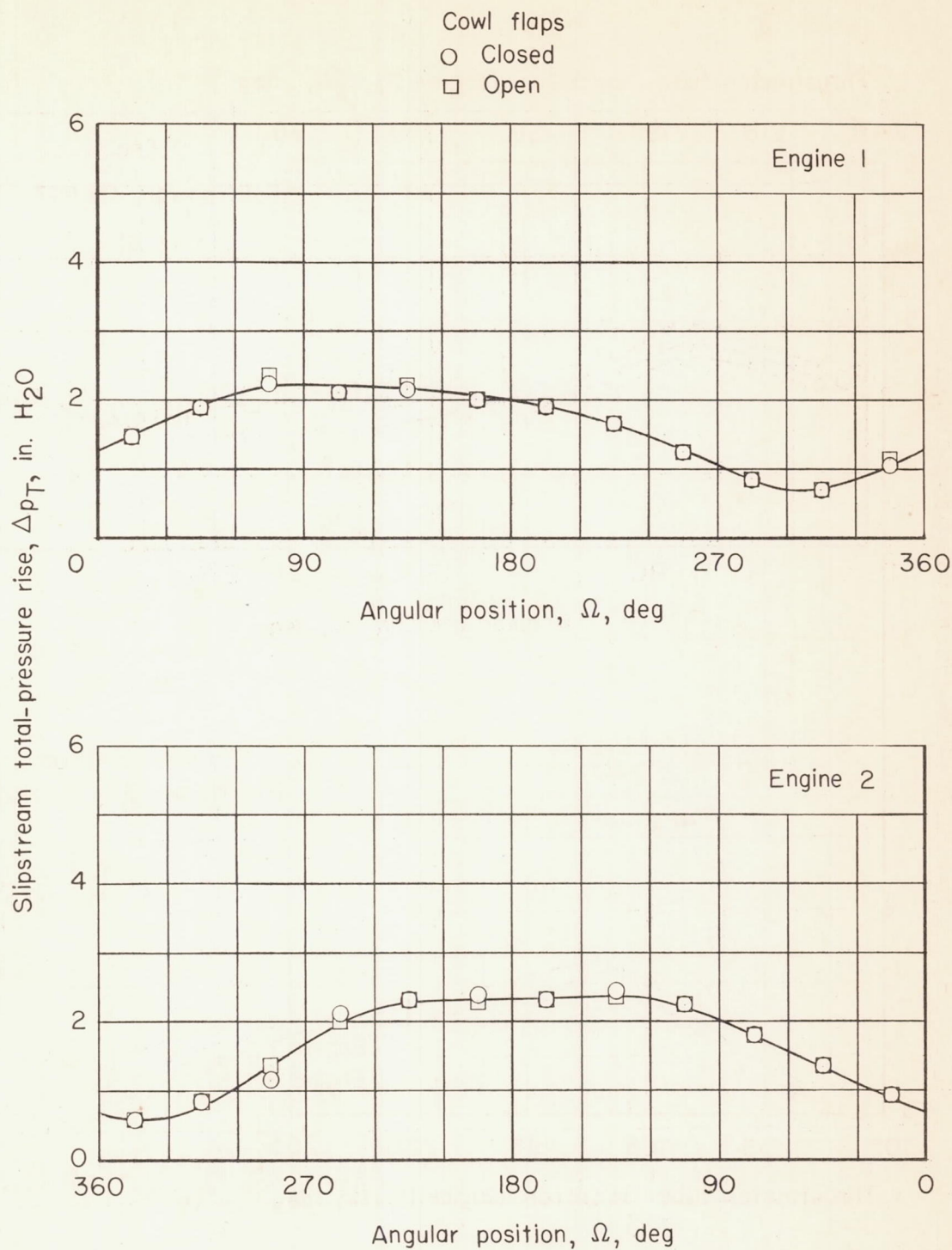


Figure 10.- Effect of engine cowl flaps at constant power condition of 2,020 rpm, manifold pressure of $19\frac{1}{2}$ in. Hg, and indicated airspeed of 110 mph.

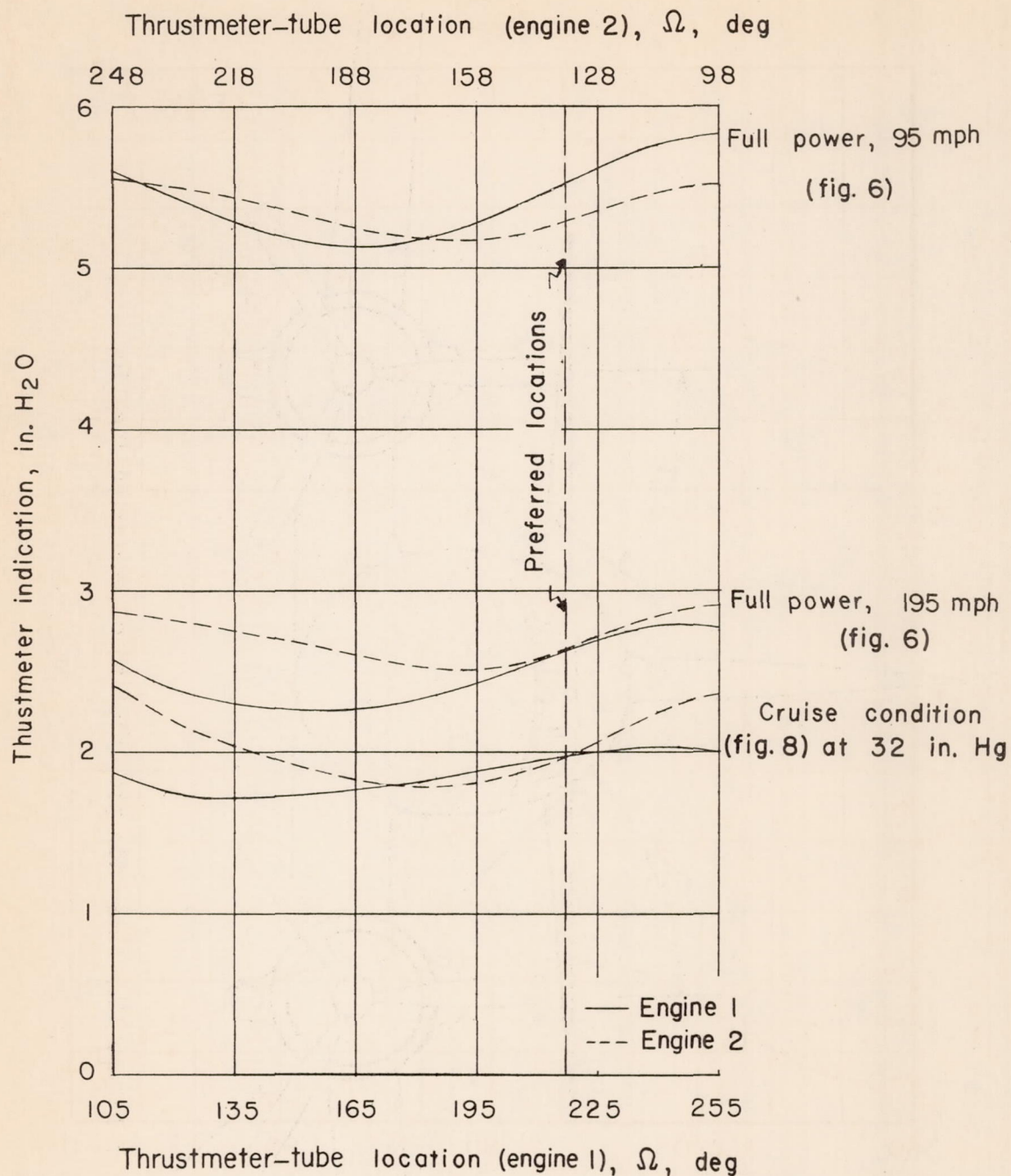


Figure 11.- Selection of preferred thrustmeter total-pressure-tube locations with emphasis on cruise operation. Twin-engine transport airplane.

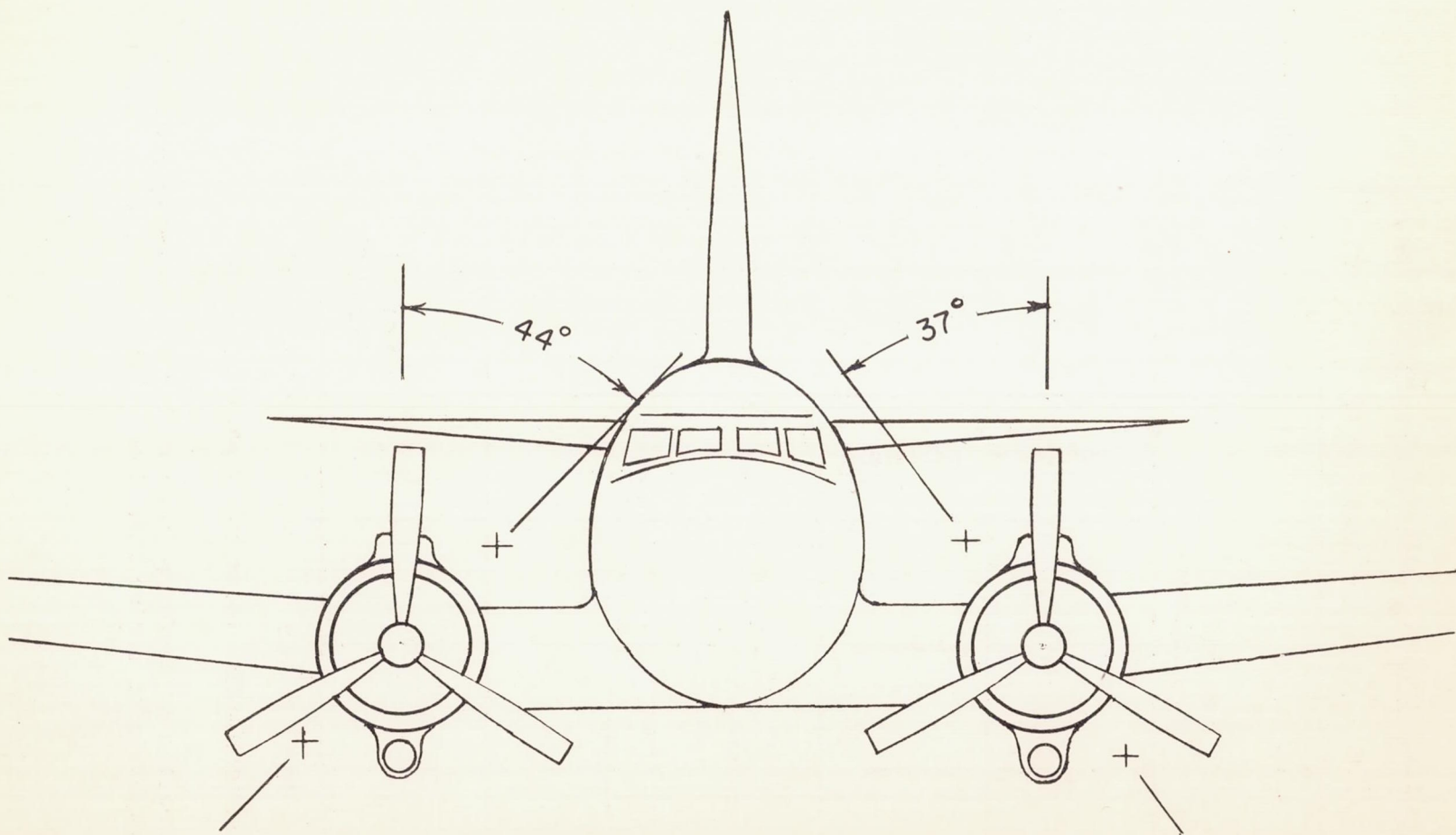


Figure 12.- Schematic presentation of preferred location.